

Review Article

Use of spray-dried animal plasma in diets for weanling pigs

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Abstract

Spray-dried animal plasma is a by-product of the meat packing industry and is considered by many to be an essential ingredient in the initial nursery diet for early-weaned pigs. With the exception of methionine, this protein source has a high concentration of amino acids. Also, spray-dried animal plasma contains a substantial amount of immunoglobulins, the most predominant being immunoglobulin G. Numerous studies have been conducted with weanling pigs to compare spray-dried animal plasma to various plant and animal protein sources. These comparative experiments have been conducted in a variety of housing environments, and represent a diversity of pig genetics, a broad range of plasma protein inclusion rates, and various plasma protein sources. In a vast majority of these studies, feeding spray-dried animal plasma has resulted in improved growth rate and feed intake. Studies conducted to determine the optimum inclusion rate of spray-dried animal plasma have been inconclusive, with the reported optimum dietary level ranging from 6 to 15%. The optimum inclusion rate of spray-dried animal plasma is likely dependent on many factors including age at weaning, level of environmental stress, health status, and complexity of the diet. Despite considerable research efforts, the specific mechanism(s) by which spray-dried animal plasma improves weanling pig performance remains unclear. Some have suggested that spray-dried animal plasma acts as a flavour or palatability enhancer, and elicits its effects solely through increasing feed intake. However, results from several different researchers have provided substantial evidence that plasma acts to improve the immunocompetence of the weaned pig, most likely mediated by the immunoglobulins found in spray-dried animal plasma.

Introduction

In recent years, many producers have adopted lactation lengths of 21 days or less in order to improve sow productivity (increased litters and pigs per sow per year), improve body condition of sows at weaning, and improve health and performance of weaned pigs by minimizing piglet exposure to sow pathogens. However, weaning pigs at these early ages creates several nutritional and management challenges due to the immaturity of both their digestive system and immune system.

At birth, the pig secretes sufficient quantities of those enzymes needed to digest the proteins and fats contained in milk. However, levels of other enzymes, especially those needed to digest more complex proteins and carbohydrates, are often insufficient until 6 to 8 weeks of age (Pekas, 1991; Jensen *et al.*, 1997; Table 1). Low levels of feed intake during the first few days following weaning have been shown to contribute to reduced levels of enzyme activity, especially pancreatic proteases, in weanling pigs (Makkink *et al.*, 1994). Also, the early-weaned pig has limited ability to secrete gastric acid (Easter, 1998). The consequence of this is the gastric pH is not sufficiently low to convert pepsinogens to pepsins, which play a key role

in initiating the breakdown of proteins. Additionally, at the time of weaning the intestinal villi often become sloughed and their surface area greatly reduced, thereby decreasing its nutrient absorptive capacity (Pluske *et al.*, 1991). Some of these changes in intestinal morphology and function are likely due to low feed intake immediately following weaning. Pluske *et al.* (1996) demonstrated that increasing the level of energy intake in weanling pigs to three times maintenance resulted in maintenance of villus height and crypt depth.

The early-weaned pig also has a limited ability to contend with disease challenges. Due to a placental structure that does not allow the transfer of maternal immunoglobulins to the fetus, pigs are born devoid of protective immunity and must rely on absorbed immunoglobulins from the sow's colostrum to provide protection against pathogens. Depending on the level of pathogen challenge, the pig's supply of colostral immunoglobulins may be used up fairly quickly. The pig's own immune system does not start to build up until about three weeks of age, and the level of immunity builds up rather slowly from this point. As a consequence, immunity can be at its lowest point in a pig's life (other than at birth) when it is weaned at an early age.

Table 1. The influence of age on total enzyme activity in the pancreas of pigs weaned at 28 days of age (mmol substrate hydrolyzed / min).

Age (days)	Trypsin	Chymotrypsin	Amylase
3	14.6	0.94	2,076
7	22.0	3.52	14,666
14	33.8	4.91	21,916
21	32.1	6.99	26,165
28	55.6	9.49	65,051
35	42.1	3.90	24,730
42	150.0	7.79	54,516
49	349.0	17.40	159,516
56	515.0	14.30	182,106

Source: Jensen *et al.*, 1997

Table 2. Typical composition of spray-dried animal plasma.

Nutrient	%
Dry matter	91.0
Crude protein	78.0
Fat	2.0
Calcium	0.15
Phosphorus	1.71
Sodium	3.02
Chloride	1.50
Arginine	4.55
Histidine	2.55
Isoleucine	2.71
Leucine	7.61
Lysine	6.84
Methionine	0.75
Cystine	2.63
Phenylalanine	4.42
Tyrosine	3.53
Threonine	4.72
Tryptophan	1.36
Valine	4.94

Source: National Research Council (1998)

Due to these digestive and immunological limitations, the ingredients that are used in the initial diet for early-weaned pigs must be chosen with care. One ingredient that is considered by many nutritionists to be an essential protein source in the initial early-weaned pig diet is spray-dried animal plasma. This paper will review research on the use of spray-dried animal plasma in diets for young pigs, and explore possible reasons for its effectiveness.

Processing and composition of spray-dried animal plasma

Spray-dried animal plasma is a by-product of the meat packing industry, and is manufactured from blood that is collected from com-

described the method used to process spray-dried animal plasma. In brief, the process begins with the bleeding of the animal and the addition of an anticoagulant to the blood, typically sodium citrate, to prevent coagulation. After collection, the plasma is separated from the erythrocytes (red blood cells) by centrifugation and chilled to approximately 4° C until further processing. The plasma is then spray-dried using a process of diffusion of the liquid plasma into a heat chamber where it is dried very quickly to a solid state to preserve protein quality. The resulting product has an off-white color and the texture of a fine powder.

Spray-dried animal plasma is a high protein ingredient with a relatively high concentration of lysine, tryptophan, and threonine, but low concentrations of methionine and isoleucine. A typical analysis of spray-dried animal plasma is shown in Table 2. A more detailed analysis of the trace mineral composition of spray-dried animal plasma can be found in Cromwell *et al.* (1999). The proteins contained in spray-dried animal plasma are primarily albumins, globins, and a₁, a₂, b₁, b₂, and g globulins. The g globulins are commonly referred to as immunoglobulins, with immunoglobulin G being the predominant antibody. Early work by Gatnau *et al.* (1989) demonstrated that the method used to process spray-dried animal plasma preserved the activity of the immunoglobulins.

Comparison of spray-dried animal plasma to other protein sources

Initial research conducted by Zimmerman (1987) found that growth rate, feed intake, and gain:feed ratio were greater for pigs consuming a corn-soybean meal-dried whey diet which contained 10% spray-dried porcine plasma than that for pigs fed 10% spray-dried blood meal or 10% flash-dried blood meal. Since that time, numerous studies have been conducted to compare spray-dried animal plasma to a variety of animal and plant protein sources for weanling pigs. The results from several of these comparative experiments are shown in Table 3. The test period in these studies ranged from 12 to 28 days in length, although in most studies the test period was 14 days. Taken together, these results represent a diversity of pig genetics, a variety of housing environments, and a fairly broad range of inclusion rates of spray-dried animal plasma. In a vast majority of these studies, spray-dried animal plasma improved pig performance to a substantial degree during the initial 2-week postweaning period. On average, spray-dried animal plasma improved daily gain by 25%, daily feed intake by 21%, and feed efficiency (gain:feed) by 4%. The responses (from Table 3) and overall trends in growth rate, feed intake, and gain:feed ratio to various levels of spray-dried animal plasma are shown in Figures 1, 2, and 3.

Comparison of different sources of spray-dried animal plasma

Many of the first studies with spray-dried animal plasma that demonstrated improved early-weaned pig performance utilized porcine plasma. Following those early successes with porcine plasma, it was questioned whether bovine plasma would elicit similar responses. Results from studies comparing these two plasma protein sources have been varied with some showing porcine plasma to be superior to bovine plasma (Hansen *et al.*, 1993; Rantanen *et al.*, 1994; Gatnau and Zimmerman, 1994; Smith *et al.*, 1995; Pierce *et al.*, 1996), while others have found bovine plasma to support pig performance equal to or greater than that for porcine plasma (Russell, 1994; Gatnau and Zimmerman, 1994; Pierce *et al.*, 1996). It is well known that the method used to process blood products, especially the processing temperature, can influence the quality of blood products (Waibel *et al.*, 1977). However, it is not clear whether the method of processing, or some other factor(s), is responsible for the observed variability. Despite these reported differences, it is generally accepted that bovine plasma is essentially equivalent to porcine plasma as a protein source for early-weaned pigs.

Table 3. Summary of experiments evaluating spray-dried animal plasma as a protein source for early-weaned pigs.

Reference	No. Pigs	Initial weight (kg)	Initial age (d)	Test period (d)	Comparative protein source ^b	Type of plasma ^c	Level of plasma (%)	ADG	ADFI	G/F
Zimmerman, 1987	18	5.72	23	14	FDBM	Porcine	10	+46	+35	+5
					SDBM	Porcine	10	+57	+38	+18
Gatnau and Zimmerman, 1990	36	6.90	NR ^a	14	CAS	Porcine	10	+6	+20	-12
					MX	Porcine	10	+88	+64	+9
					ISP	Porcine	10	+71	+72	+10
Gatnau and Zimmerman, 1990	36	6.90	NR ^a	14	SBM	Porcine	10	+81	+73	+7
					DSM	Porcine	10	+50	+54	+29
Gatnau and Zimmerman, 1991	96	7.10	NR ^a	14	SBM	Porcine	10	+102	+76	+12
					BM	Porcine	10	+119	+61	+44
Sohn <i>et al.</i> , 1991	144	NR ^a	24	14	DSM	Porcine	4	+29	+24	+1
					SDWB	Porcine	4	+13	+11	0
Gatnau, <i>et al.</i> , 1991	35	7.10	28	14	SBM	Porcine	6	+82	+34	+60
Gatnau and Zimmerman, 1992	96	6.10	25	14	SBM	Porcine	8	+78	+41	+31
Richert <i>et al.</i> , 1992	132	3.80	NR ^a	14	DSM	Porcine	NR ^a	+15	+22	-7
					WPC	Porcine	NR ^a	+14	+19	-5
					DB	Porcine	NR ^a	+24	+38	-12
Hansen <i>et al.</i> , 1993	236	7.50	24	14	DSM	Porcine	10	+2	-1	+4
Hansen <i>et al.</i> , 1993	204	5.90	21	14	DSM	Porcine	10	+33	+25	+6
					SBM	Porcine	10	+28	+17	+9
					DSM	Porcine	10	+15	+28	-11
Hansen <i>et al.</i> , 1993	120	5.30	21	14	PBM	Porcine	10	+11	+23	-10
					MX	Porcine	10	+44	+22	+15
					DSM	Bovine	4	0	+8	-8
					PBM	Bovine	4	-4	+4	-7
					MX	Bovine	4	+24	+3	+18
					DSM	Porcine	10	+55	+46	+6
Kats <i>et al.</i> , 1994	534	6.40	21	14	DSM	Porcine	10	+55	+46	+6
Kats <i>et al.</i> , 1994	298	5.50	19	14	SDBM	Porcine	10	0	+2	-1
Rantanen <i>et al.</i> , 1994	626	4.10	13.2	14	DSM	Porcine	6	+28	+30	-3
					DSM	Bovine	6	+23	+22	0
Veum and Halley, 1994	135	6.74	21	14	DSM	Porcine	10	+1	+9	-8
Veum and Haque, 1994	108	6.81	21	14	SDPB	Porcine	10	-16	+6	-20
Pendergraft <i>et al.</i> , 1994	120	6.40	NR ^a	14	DSM	Porcine	NR ^a	+10	+5	+5
					WG	Porcine	NR ^a	+13	+15	-2
Coffey and Cromwell, 1995	80	5.30	18	14	DSM	Porcine	8	+5	+17	-10
					DSM	Porcine	8	+40	+59	-12
Coffey and Cromwell, 1995	80	5.40	18	14	DSM	Porcine	8	+6	+18	-10
					DSM	Porcine	8	+24	+31	-5
Coffey and Cromwell, 1995	120	7.30	30	14	SBM	Porcine	5	+69	+54	+10
					DSM	Porcine	5	+53	+57	-3
					DSM	Porcine	5	+41	+34	+5
De Rodas <i>et al.</i> , 1995	144	7.20	24	14	DSM	Porcine	4	+29	+24	+1
					SDBM	Porcine	4	+13	+11	-1

Table 3 (Continued). Summary of experiments evaluating spray-dried animal plasma as a protein source for early-weaned pigs.

De Rodas <i>et al.</i> , 1995	18	6.10	19.5	14	SBM	Porcine	14	+29	+21	+10
Richert <i>et al.</i> , 1995	230	5.00	18	14	HM	Porcine	8	+62	+33	+22
Smith <i>et al.</i> , 1995	416	4.30	15	14	DSM	Porcine	5	+22	+8	+13
					DSM	Bovine	5	+9	+7	+3
Weaver <i>et al.</i> , 1995	100	6.70	NR ^a	14	CAS	Porcine	8	+13	+22	-11
Owen <i>et al.</i> , 1995	216	4.50	21	14	DSM	Porcine	7.5	+17	+31	-10
Owen <i>et al.</i> , 1995	168	3.20	10	21	DSM	Porcine	10	+11	+7	+4
Pierce <i>et al.</i> , 1995a	80	6.10	21	21	SPC	Porcine	8	+3	+11	-8
Pierce <i>et al.</i> , 1995a	80	6.10	21	21	SPC	Porcine	8	+2	+12	-9
Pierce <i>et al.</i> , 1995b	90	5.30	14	14	SPC	Porcine	8	+34	+47	-9
Lindemann <i>et al.</i> , 1996	265	5.70	21	28	SBM	Porcine	6	+34	+9	+23
					EDP	Porcine	6	+2	-1	+4
Pierce <i>et al.</i> , 1996	95	5.60	19.7	14	SPC	Bovine	8	+12	+18	-5
					SPC	Porcine	8	+53	+58	-3
Pierce <i>et al.</i> , 1996	152	6.40	22.5	14	SPC	Bovine	8	+18	+21	-3
					SPC	Porcine	8	+16	+28	-9
Woodgate <i>et al.</i> , 1997	72	5.50	19	21	UP	Animal	6	0	-3	+3
Bergstrom <i>et al.</i> , 1997	300	4.00	14	14	SBM	Animal	5	+3	+2	+1
Bergstrom <i>et al.</i> , 1997	324	3.90	12	14	SBM	Animal	2.5	+6	+1	+5
Kerr <i>et al.</i> , 1997	180	5.90	20	14	EPP	Animal	7	-12	+2	-14
Wright <i>et al.</i> , 1998	216	6.20	21	10	SBM	Animal	3.75	+8	-19	+33
Koehler <i>et al.</i> , 1998	218	6.10	19	14	FM	Porcine	4	+46	+34	+9
					DPS	Porcine	4	+18	+14	+4
Lindemann <i>et al.</i> , 1998	155	6.60	21	28	SBM	Porcine	6	+17	-1	+19
					DPS	Porcine	6	-10	-10	0
Campbell <i>et al.</i> , 1998 ^d	135	5.79	21	14	SPC	Animal	5	+19	+16	+3
Campbell <i>et al.</i> , 1998 ^d	240	5.80	17	14	SPC	Animal	7.5	+10	+15	-4
Maxwell <i>et al.</i> , 1999	216	NR ^a	18	10	SBM	Porcine	4	+64	+11	+47
Carter <i>et al.</i> , 1999	96	6.62	NR ^a	14	DFS	Animal	2.5	+19	+6	+12
					DPS	Animal	2.5	+15	+7	+8
Grinstead <i>et al.</i> , 2000	180	5.80	19	14	DSM	Animal	5	0	+4	-3
					WPP	Animal	5	-4	+3	-7
Grinstead <i>et al.</i> , 2000	180	5.10	17	14	SBM	Animal	5	+27	+13	+12
					WPP	Animal	5	+5	+12	-6
Grinstead <i>et al.</i> , 2000	310	4.20	12.5	14	WPP	Animal	6.7	-4	-2	-1
Cromwell <i>et al.</i> , 2000	318	6.50	21	14	SBM	Animal	5	+12	-1	+13
					AL	Animal	5	+1	+4	-3
Overall summary from comparative studies										
Total number of pigs:	8448									
Simple means:		5.79	19.7	15.0			7.0	+25	+21	+4
No. comparisons:								79	79	79
No. positive responses:								70	70	42
Percent positive responses:								89	89	53

^aNR, not reported.

^bAL, Amino-LacTM; BM, blood meal; CAS, casein; DB, dried buttermilk; DFS, dried fish solubles; DPS, dried porcine solubles; DSM, dried skim milk; EDP, enzymatically digested protein; EPP, experimental potato protein; FDBM, flash-dried blood meal; FM, fish meal; HM, herring meal; ISP, isolated soy protein; MX, meat extract; PBM, porcine blood meal; SBM, soybean meal; SDBM, spray-dried blood meal; SDPB, spray-dried poultry byproduct; SDWB, spray-dried whole blood; SPC, soy protein concentrate; UP, Ultimate Protein 1672; WG, wheat gluten; WPC, whey protein concentrate; WPP, whey protein product.

^cBovine, porcine, or a mixture of the two sources.^dData from Discoveries (Quarterly Technical Update by American Protein Corporation).

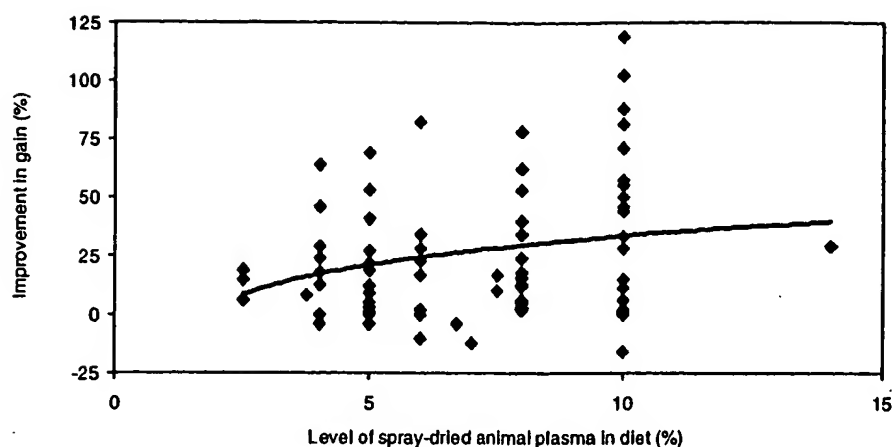


Figure 1. Improvement in growth rate from spray-dried animal plasma

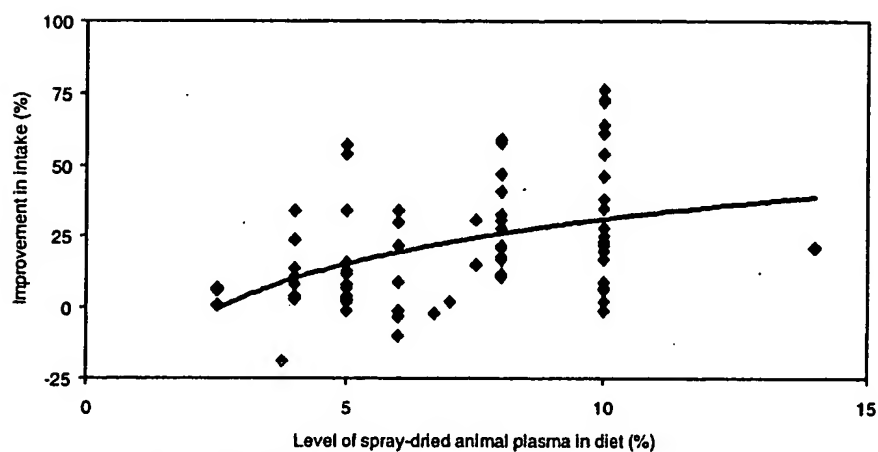


Figure 2. Improvement in feed intake from spray-dried animal plasma

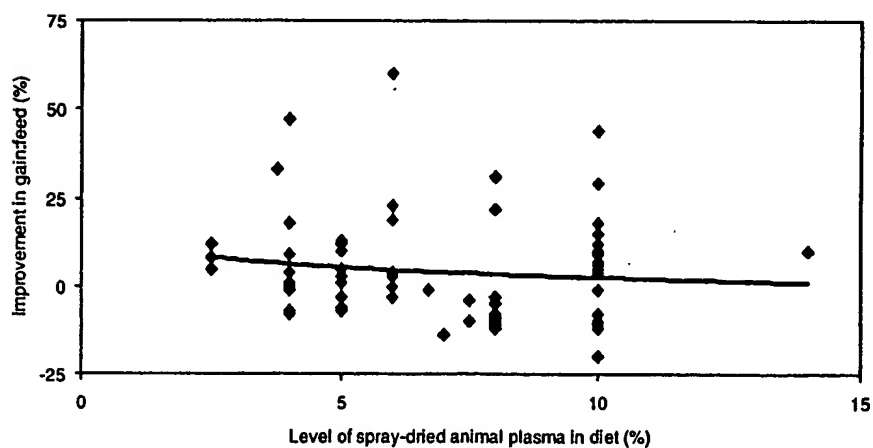


Figure 3. Improvement in gain:feed ratio from spray-dried animal plasma

Several manufacturers have also been working to develop more standardized or improved blends of plasma protein products. For example, a granular plasma protein product (AppeteinTM; American Protein Corporation) that has been standardized with respect to levels of plasma, serum, and globulin protein has recently been released, as has a water-soluble globulin protein source (SoluteinTM; American Protein Corporation). Other plasma protein products include a blend of spray-dried animal plasma and hydrolyzed porcine proteins (ProBlendTM-65; Farmland Industries, Inc.) and a combination of porcine globulin and hyperimmunized egg proteins (ProtiOneTM; DuCoa). Table 4 shows the results of a few studies comparing some of these plasma protein products to soybean meal,

soy protein concentrate, and spray-dried animal plasma. With the exception of feed intake in one study, pigs fed these plasma protein products had improved growth rate, feed intake, and feed efficiency compared to those fed soybean meal or soy protein concentrate, with overall improvements of 30%, 9%, and 21% respectively. The results from comparisons of these products to spray-dried animal plasma are more variable. Depending on the study, these products were inferior, equal, or superior to spray-dried animal plasma. Overall, gains, feed intakes, and gain:feed ratios were 5%, 3%, and 3% greater, respectively, for the plasma protein products than for spray-dried animal plasma.

Table 4. Summary of experiments comparing spray-dried animal plasma to other plasma protein products in diets for early-weaned pigs.

Reference	No. pigs	Initial weight (kg)	Initial age (d)	Test period (d)	Comparative protein source ^b	Plasma protein product ^c	Plasma product level (%)	Improvement from plasma protein product over comparative protein source (%)	Reference	No. pigs
Wright <i>et al.</i> , 1998	216	6.20	21	10	SBM	ProBlend TM -65	NR ^a	+9	-6	+20
					SDPP	ProBlend TM -65	NR ^a	+1	+16	-10
Campbell <i>et al.</i> , 1998 ^d	135	5.79	21	14	SPC	Appetein TM	5	+28	+21	+6
					SDAP	Appetein TM	5	+7	+4	+3
Campbell <i>et al.</i> , 1998 ^d	240	5.80	17	14	SPC	Appetein TM	7.5	+16	+12	+3
					SDAP	Appetein TM	7.5	+5	-2	+8
Maxwell <i>et al.</i> , 1999	216	NR ^a	18	10	SBM	ProBlend TM -65	4	+45	+10	+32
					SDPP	ProBlend TM -65	4	-12	-1	-11
					SBM	Appetein TM	4	+54	+6	+45
					SDPP	Appetein TM	4	-6	-5	-2
Shipp and Godfredson-Kisic, 1999	200	NR ^a	14	14	SDPP	ProtiOne TM	2	+8	+5	+3
DuCoa, 2000a ^e	164	NR ^a	14	13	SDPP	ProtiOne TM	4	+19	+3	+15
DuCoa, 2000b ^e	930	5.53	21	7	SDPP	ProtiOne TM	4.25	+20	+3	+16

Overall summary from comparative studies (2101 total pigs)

Plasma protein products versus soybean meal or soy protein concentrate:

Simple means:	5.93	19.3	12.0	5.1	+30	+9	+21
No. comparisons:					5	5	5
No. positive responses:					5	4	5
Percent positive responses:					100	80	100

Plasma protein products versus spray-dried animal plasma:

Simple means:	5.83	18.0	11.7	4.4	+5	+3	+3
No. comparisons:					8	8	8
No. positive responses:					6	5	5
Percent positive responses:					75	63	63

^aNR, not reported.

^bSBM, soybean meal; SDAP, spray-dried animal plasma; SDPP, spray-dried porcine plasma; SPC, soy protein concentrate.

^cProBlendTM-65 (Farmland Industries, Inc.) is a blend of porcine plasma protein and high quality hydrolyzed porcine proteins derived from the packing industry. AppeteinTM (American Protein Corporation) is a granular plasma protein product that has been standardized for plasma, serum, and globulin content. ProtiOneTM (DuCoa) is a protein product consisting primarily of porcine globulin and hyperimmunized egg proteins.

^dData from *Discoveries* (Quarterly Technical Update by American Protein Corporation).

^eData from *DuCoa Technical Reports*.

Optimum inclusion rate of spray-dried animal plasma

In many of the studies comparing spray-dried animal plasma to other sources of protein for early-weaned pigs, an arbitrary inclusion level of animal plasma was chosen. Only a few studies have attempted to quantify the level of spray-dried animal plasma that is needed to maximize weanling pig performance. Studies by Gatnau *et al.* (1991) and Gatnau and Zimmerman (1992), using 28- or 25-day old pigs, respectively, suggested that rate and efficiency of gain and feed intake during the first two weeks following weaning were maximized with 6% spray-dried plasma protein in the diet. However, a closer examination of the diets fed in these studies would indicate that the amino acid methionine might have been limiting when the dietary level of spray-dried porcine plasma exceeded 6%. Results from an experiment by Kats *et al.* (1994) demonstrated that performance of 21-day old nursery pigs was improved with up to 10% dietary spray-dried porcine plasma when the level of methionine in the diet was maintained at or above the pigs' requirement. Using 10-day old pigs, Drits *et al.* (1994) found that growth rate and feed intake for the initial 14 days postweaning increased linearly with inclusion rates up to 15% spray-dried porcine plasma.

The optimum inclusion rate of spray-dried animal plasma is likely dependent upon many factors including age at weaning, level of environmental stress, degree of pathogen exposure, and nutrient density and complexity of the diet. Depending on its price, most nutritionists will recommend a dietary level of spray-dried animal plasma ranging from 2 to 8% when fed under practical nursery conditions.

Mode of action of spray-dried animal plasma

Considerable research has been devoted to evaluating the means by which spray-dried animal plasma produces improvements in weaned pig performance. However, despite this effort, the specific mechanism(s) remains unclear.

The fact that spray-dried animal plasma provides a highly available supply of amino acids may account for some of the improvements in weaned pig performance. It has also been speculated that biologically active growth factors (such as insulin-like growth factor-I; IGF-I) found in spray-dried animal plasma may be responsible for the improvements in pig performance. However, de Rodas *et al.* (1995) found that feeding spray-dried porcine plasma did not appear to involve a change in plasma IGF-I, though it did result in an increase in plasma levels of growth hormone (GH). Nonetheless, more research is needed before one can completely discount the notion that biologically active molecules in spray-dried animal plasma elicit an effect.

One of the more consistently reported responses to feeding spray-dried animal plasma is an increase in feed intake immediately after weaning compared to other protein sources. In fact, the magnitude of increase in feed intake often closely mirrors the magnitude of increase in growth rate. For this reason, some have hypothesized that spray-dried animal plasma acts as a flavour or palatability enhancer, and improvements in pig performance are due solely to its effect on feed intake. Support for this theory comes from a diet preference study conducted by Ermer *et al.* (1994). In a 21-day study comparing diets containing either 20% dried skim milk or 8.5% spray-dried porcine plasma fed to weanling pigs, 28 of the 35 pigs preferred the diet containing porcine plasma. Additionally, the porcine plasma diet accounted for 60% of feed consumption on day 2 and for 71% of feed consumption on day 21. These authors suggested that diets containing spray-dried porcine plasma may be more palatable than diets containing dried skim milk.

However, there is a growing body of evidence that would indicate that spray-dried animal plasma enhances pig performance by improving the immunocompetence of the young pig, most likely mediated by the immunoglobulins present in spray-dried animal plasma. Early research by Gatnau *et al.* (1989) found that the immunoglobulins in spray-dried porcine plasma were absorbed from the intestinal lumen to the blood stream in colostrum-deprived, newborn pigs, and that titers for porcine parvovirus and porcine rotavirus could be measured in these pigs after absorption of the immunoglobulins. Although it is unlikely that the immunoglobulins present in spray-dried animal plasma are absorbed across the intestinal wall in the early-weaned pig, it may be that these immunoglobulins prevent viruses and bacteria from damaging the gut wall, thereby resulting in a more functional intestinal wall. A reduction in damage to the intestinal wall could explain why several researchers (Gatnau and Zimmerman, 1991; Van der Peet-Schwering and Binnendijk, 1995; Cain and Zimmerman, 1997) have found that weaned pigs fed a diet containing spray-dried animal plasma had a lower incidence of diarrhea than those fed more traditional sources of protein. This is further supported by studies which demonstrated that pigs fed spray-dried animal plasma had improved intestinal morphology and enzyme activity as evidenced by increased villus surface area (Gatnau *et al.*, 1995), longer villi and higher villus:crypt ratio (Touchette *et al.*, 1997; Spencer *et al.*, 1997), and increased mucosal maltase and lactase activity (Cain *et al.*, 1992; Gatnau *et al.*, 1995).

Researchers have also found that improvements in pig performance due to spray-dried animal plasma are more pronounced when pigs are raised in an environment where potential exposure to pathogens is higher. Coffey and Cromwell (1995) found that the magnitude of the growth response was greatest when pigs were housed in a continuous flow, on-farm nursery as compared to housed in an off-site, experimental nursery where pigs were managed on an all-in-all-out basis. Somewhat similar results have been reported by Gatnau and Zimmerman (1991). Furthermore, Stahly *et al.* (1995) found that dietary plasma protein enhanced both rate and efficiency of gain in pigs with a high degree of antigen exposure, but not in pigs with a low degree of antigen exposure.

Data from studies evaluating the separated components of spray-dried animal plasma provide additional credence for the notion that the immunoglobulins are largely responsible for improvements in pig performance. The major protein components of porcine plasma are fibrin, low molecular weight fraction (< 10,000 MW), medium molecular weight fraction (albumin; 10,000 to 100,000 MW), and high molecular weight fraction (immunoglobulins; > 100,000 MW). The results obtained from studies comparing diets containing these separated fractions to diets containing spray-dried animal plasma have shown that the high molecular weight fraction, or immunoglobulin fraction, is responsible for the beneficial effects (Cain, 1995; Gatnau *et al.* 1995; Owen *et al.* 1995; Pierce *et al.* 1995a; Weaver *et al.* 1995).

Finally, a recent series of experiments by Touchette *et al.* (1999a; 1999b; 2000a; 2000b) provides further substantiation that spray-dried animal plasma may improve the immune status of the early-weaned pig. These authors reported that weanling pigs fed spray-dried animal plasma, compared to pigs not receiving spray-dried animal plasma, had lower levels of hypothalamic corticotropin releasing hormone (CRH), decreased CRH receptor mRNA in the pituitary, and decreased adrenal ACTH receptor mRNA (Touchette *et al.*, 2000a), indicating a reduction in the basal activation level of the hypothalamic-pituitary-adrenal axis. Also, it was found that following an immunological challenge using either lipopolysaccharide (LPS; Touchette *et al.*, 1999a) or *E. coli* (Touchette *et al.*, 1999b), pigs fed spray-dried animal plasma had a greater hypothalamic-pituitary-adrenal axis response.

itary-adrenal axis response as evidenced by increased serum levels of adrenocorticotrophic hormone (ACTH) and cortisol. Because pathogen exposure is known to be a stimulator of the hypothalamic-pituitary-adrenal axis, these responses may indicate a reduction in immune system activation due to feeding spray-dried animal plasma. This may explain why pigs fed spray-dried animal plasma had increased serum levels of tumor necrosis factor- α (TNF- α) and interferon- γ (IFN γ) following a LPS challenge (Touchette *et al.*, 2000b). Thus, it appears that the hypothalamic-pituitary-adrenal axis of pigs fed spray-dried animal plasma may be less activated than that of pigs fed a diet without spray-dried animal plasma, perhaps indicating that spray-dried animal plasma makes the pigs more immunologically naïve and more susceptible to immunological challenge.

Conclusions

Data from experiments conducted to date indicate that inclusion of spray-dried animal plasma in diets for early-weaned pigs stimulates feed intake and improves rate and efficiency of gain during the initial 2 weeks after weaning. The specific mode of action that elicits these responses is not completely clear, but most of the evidence indicates that the immunoglobulins present in spray-dried animal plasma are responsible. However, other factors that may play a role include protein quality, biologically active growth factors, flavour or palatability, combinations of these factors, and (or) other unidentified factors.

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